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COMBATING APPLE SCAB

Spraying and Dusting Experiments in 1923 with Summary of Three Years' Results

By WILLIAM L. DORAN and A. VINCENT OSMUN

Recently completed studies on apple scab and its control show that development of this disease may be prevented through the use of a number of different materials — lime-sulfur, dry lime-sulfur, or copper sprays followed by lime-sulfur, may be effectively used, as also dusts of various kinds. Scab development is governed largely by weather conditions; possibility of successful control, by the proper timing of protective treatment and efficiency in the actual spraying and dusting work. These facts are brought out in this bulletin, which is the final report of a three-year investigation. Tabulated results of the work carried on in 1923 are presented, likewise a summarization of all data collected during the course of the study.

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AGRICULTURAL EXPERIMENT STATION
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COMBATING APPLE SCAB.

SPRAYING AND DUSTING EXPERIMENTS IN 1923[1] WITH SUMMARY OF THREE YEARS' RESULTS.

By WILLIAM L. DORAN and A. VINCENT OSMUN.

INTRODUCTION.

Scab has long been a disease to reckon with in the apple orchards of Massachusetts, but not until the advent and extensive planting of the McIntosh, a variety particularly susceptible to attack by the scab fungus, did it become a menace of large proportions. As more and more of the McIntosh orchards came into bearing, an increasing number of growers experienced difficulty in controlling the disease and losses became so large as to seriously threaten the orchard industry. Finally, in 1920, appeal was made to the Station by the growers, and in the fall of that year the Station entered into a cooperative agreement with the Nashoba Fruit Producers' Association under which experiments on the control of scab were planned and undertaken by the Department of Botany.

The results of the spraying and dusting experiments of the first two seasons already have been reported by Krout (1) (2).[2] The present report is on the work of 1923, together with such references to the work in Massachusetts in 1922 and 1921 as will assist in making points clear. The results of the three years' experiments are summarized in Table III (page 17). Other references in this report are for the most part to spraying and dusting experiments conducted within the last two years, especially in the northeastern states.

The general objectives of the investigations in 1923 were to secure more light on the following questions in regard to the control of apple scab:

1. What is the effect of the addition to the spray schedule of a prepink application?
2. How does dry lime-sulfur compare with liquid lime-sulfur in fungicidal efficiency?
3. What is the ratio of dry lime-sulfur to water, at which this fungicide is dependable?
4. What is the effect of the addition of calcium caseinate spreader to the fungicide when applied as a dust and as a spray?
5. How does a spray schedule consisting of lime-sulfur throughout the season compare with a schedule in which Bordeaux mixture is substituted for the application or applications before flowering?
6. How does Atomic Sulphur compare with dry and liquid lime-sulfur for the control of scab?
7. Does the addition of lime or of calcium caseinate to the combination lime-sulfur-lead arsenate spray improve the mixture?
8. For the control of apple scab, what is the fungicidal efficiency of sulfur dust? What is the effect of substituting a copper-lime-arsenic dust for the prepink and pink applications?

The rainy summer of 1922 was especially suitable for the experimental work, because of the abundant infection on unsprayed trees. The summer of 1923 was much drier; there was a rainfall of only 7.29 inches in May, June and July, as compared with 20.14 inches in the same period in 1922. This naturally resulted in less infection, but there was sufficient infection on unsprayed trees in every case but one to justify the drawing of conclusions as to the relative values of the several treatments applied.

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[1] The experiments here described were conducted in the orchards of Harry L. Knights of Littleton, H. L. Frost of Littleton, Stephen W. Sabine of Groton, and A. N. Stowe of Hudson. The superintendents of these orchards are Roy C. Wilbur of the Frost Farm, John J. Collins of the Stowe Farm, and J. W. Ames of the Knights Farm. Acknowledgment is due these men for placing their orchards at the disposal of the Experiment Station, and for cooperating in the investigations. Acknowledgment is also due to the Nashoba Fruit Producers' Association for their cooperation.

[2] Numbers in parenthesis refer to literature cited, see page 13.

The results, as given in tables I and II, and in the text, are expressed in percentage of scabby apples present in the check and in each sprayed or dusted plot. In interpreting the results of any spraying or dusting experiments, the percentage of infection in the check is of primary importance. If this is low, the data are correspondingly of less value, since it cannot be said that the fungicidal treatment was put to a real test. The percentage of infection on the unsprayed trees in the Sabine orchard where some of the spraying experiments were conducted was so low that the results in that orchard are not considered in this report.

Methods and Materials Used.

The trees used for these experiments were of the McIntosh variety. Each orchard was divided in such a way that the check plot was as nearly as possible like the treated plots in every way except fungicidal treatment received. The check plots received no treatment for scab control, but did receive a calyx application with insecticides only. All check plots were surrounded by or contiguous to the treated plots. In dividing an orchard for a dusting experiment, it is difficult to so locate the check plot that it will not receive some dust as the dust drifts through the orchard. If it were possible to prevent this entirely, the percentage of scabby fruits on the dust checks would probably be larger.

The following treatments were tested or compared:

1. Dry lime-sulfur 3–50 for the pink, calyx and one later application.
2. Dry lime-sulfur 3–50 with calcium caseinate added for the pink, calyx, and one later application.
3. Dry lime-sulfur 2–50 for the pink, calyx and one later application.
4. Dry lime-sulfur 4–50 for the pink, calyx and one later application.
5. Dry lime-sulfur 3–50 for the prepink, pink, calyx and one later application.
6. Bordeaux mixture 3–10–50 for the prepink and pink applications followed by liquid lime-sulfur 1–50 for the calyx and one later application.
7. Bordeaux mixture 3–10–50 for the pink application followed by liquid lime-sulfur 1–50 for the calyx and one later application.
8. Atomic Sulphur for the pink, calyx and one later application.
9. Liquid lime-sulfur for the pink, calyx and one later application.
10. Bordeaux mixture 3–10–50 for the pink application followed by dry lime-sulfur 4–50 for the calyx, and one later application.
11. Liquid lime-sulfur with lime added for the pink, calyx and one later application.
12. Copper dust for the prepink and pink applications followed by sulfur dust for the calyx and two later applications.
13. Sulfur dust for the prepink, pink, calyx and two later applications.
14. Sulfur dust with calcium caseinate added for the prepink, pink, calyx and two later applications.

In one orchard, the dusting schedule began with the pink instead of the prepink application.

An examination of Tables I and II will show which treatment each of the thirty-five plots received, including the fungicide and its dilution used at each application, together with the date of each application.

Rates of Application.

About four gallons of spray per tree per application were used for trees twelve to fifteen years old. About one and one-half pounds of dust per tree of this size were used at each application.

Liquid lime-sulfur was used at the rate of one gallon in fifty gallons of water. Dry lime-sulfur was used at the rate of two, three or four pounds in fifty gallons; this is expressed in abbreviated form in the text as dry lime-sulfur 2–50, 3–50, etc. It was not found necessary to add water to this material before placing it in the spray tank; in fact, to do so resulted in increased lumpiness. A more satisfactory method is to sift this material into the nearly filled spray tank with the agitator running.

Calcium caseinate spreader (which is sold under various trade names, such as Kayso, Spracein, etc.) was used at the rate of 1 pound in 100 gallons, or it was

added to sulfur dust so that the dust mixture would contain 5 per cent calcium caseinate.

The copper dust (used only before the flower buds opened) contained 11 per cent dehydrated copper sulfate. The sulfur dust contained 92 per cent sulfur and 8 per cent inert ingredients. When it was desired to apply an arsenical also to dusted trees, a dust containing sulfur and lead arsenate in the ratio 90:10 or 85:15 was used.

Arsenate of lead and nicotine sulfate (Black Leaf 40) in the usual proportions were added to the sprays for each application, except for the fourth summer spray when nicotine sulfate was omitted.

The spraying was done with power sprayers with about 200 pounds pressure, using Pilot rods or regular spray rods.

The dusting was done with power dusters, either Perfect or Niagara. The duster was driven along both sides of each row of trees, so that dust was applied to each tree from opposite sides. Dusting is not a pleasant operation, because of the pain caused by the sulfur getting into the eyes. Goggles, although somewhat of a nuisance, appear to be a necessity when much dusting is to be done. Some difficulty was experienced in thoroughly dusting the tops of tall trees. Krout (2) and Childs (3) both mention this. The tops of taller trees cannot be thoroughly coated with dust when any wind is blowing. The dusting was done early in the morning, beginning about five o'clock in most cases. The foliage was not always wet, however. There is no experimental evidence of the necessity of dusting only when the foliage is wet.

Friez hygro-thermographs and rain gauges were maintained in the Frost and Sabine orchards. The data on rainfall secured in the orchards is not considered complete, and the precipitation data given in this report are from the Concord observer for the United States Weather Bureau as recorded in Climatological Data for New England.

Because of the large yield of fruit, it was manifestly impossible to examine every apple in a plot at picking time. For this reason, four representative trees were selected from each plot for examination of the fruit. About 150,000 apples were examined. Since much of the infection was late, most of the scabby apples even on the check plots were marketable. Apples designated as scabby in the data include both marketable-scabby, and unmarketable scabby.

Effect of the Addition of a Prepink Application to the Schedule.

The delayed dormant application is made just as the buds are breaking or when the first tips of green show. The pink application is usually understood to mean that which is applied as soon as the blossom buds separate in the clusters, while they show pink, but before they begin to open. Any application of a summer-strength fungicide made between the delayed dormant and the pink applications may be spoken of as a prepink application. The interval between the prepink and pink applications, which will depend upon the weather and consequent rapidity of growth, is bound to be short. In the case of large orchards, there is likely to be no interval, so that an application begun as a prepink will end as a pink, as regards the development of the flower buds. The first summer application, either prepink or pink, should be made when the tree is first in danger of infection, that is, before the first discharge of winter spores from the dead leaves beneath the tree. It is probable that many of the failures to control apple scab in Massachusetts have occurred because this first summer spray was too long delayed. The prepink cannot be regarded as a substitute for the pink application. If a prepink application is necessary, a pink is none the less so, because new growth has exposed new and unprotected leaf surface to the danger of infection.

The beginning of the period when the tree is in danger of infection can be determined only by "trapping" the winter spores on adhesive-coated glass slides inverted over the dead leaves and microscopic examination of the slides, after the method described by Wallace (4) and Childs (5). In some years, winter spores are mature and ready to be discharged, if the dead leaves containing them are wet, while the apple buds are only beginning to swell. In such years, it is evident that if the first application is deferred until the flower buds show pink, some infection is

likely to occur before that time. Because a prepink application is proved necessary or unnecessary one year, it does not follow that the reverse may not be true the next year. A prepink application made in the absence of information as to the development and condition of the winter spores is to be regarded as insurance.

Krout (2) in 1922 tested the addition of a prepink application to the spray schedule. In the first orchard, the addition of the prepink application was not followed by a decrease in the percentage of scab but rather by an increase of 3 per cent. In each of two other orchards the prepink spray apparently reduced the scab 1 per cent. It is evident, therefore, that in 1922 no real benefit from the use of the prepink spray was shown, as compared with a schedule which included only a pink application before the flowers opened.

In 1923, spray schedules with and without a prepink application were tested in two orchards. In the Frost orchard trees sprayed with lime-sulfur beginning with the pink application yielded 7.06 per cent scabby fruit and when this material was used beginning with the prepink application, there was only 1.2 per cent scab, a significant reduction. Where Bordeaux mixture was used for the pink application, followed by lime-sulfur for the later applications, there was 1.7 per cent scabby fruit, and on the plot where this schedule was modified by the addition of a prepink application of Bordeaux mixture, only 0.6 per cent scabby fruit was produced. Here again there was a reduction in the percentage of scab, although such a small one as to be probably without significance.

In the Knights orchard, trees sprayed with dry lime-sulfur 4–50 beginning with the pink application, yielded 1.7 per cent scabby fruit, and where dry lime-sulfur 3–50 was applied beginning with the prepink spray, there was 4.8 per cent scabby fruit. Since the strength of the material was different the addition of a prepink application was not the only changed factor affecting the control of the disease. When the cost of the material and the cost of the labor for each application are considered, however, it is evident that three applications of dry lime-sulfur 4–50 beginning with the pink were a more profitable treatment than four applications of dry lime-sulfur 3–50 beginning with the prepink. There was 1.06 per cent scabby fruit on the trees sprayed with Bordeaux mixture beginning with the pink application and dry lime-sulfur 4–50 for the later applications. As compared with this there was 4.9 per cent scabby fruit on trees sprayed with Bordeaux mixture for the prepink and pink applications followed by liquid lime-sulfur for the later applications. Since, as is shown elsewhere in this report, we may regard liquid lime-sulfur as of equal fungicidal efficiency with dry lime-sulfur 4–50, it is evident that the addition of a prepink application did not reduce the percentage of scab; instead, it was followed by an increase of 3.84 per cent. The need of a prepink application is not shown by the data of either 1922 or 1923.

When we consider dusting, however, the case may be entirely different. In the two orchards where the dusting schedule began with a prepink application, a good control of scab was secured. In the orchard where only one application, the pink, was made before the flower buds opened a much poorer control resulted. Satisfactory experimental evidence on this point, however, would necessitate that the two schedules, with and without a prepink application, be used in adjoining parts of the same orchard with one check for the two.

The Use of Dry Lime-Sulfur.

Arguments for and against the use of dry lime-sulfur as compared with the liquid form include, of course, considerations of the relative costs, convenience in handling, and effect on the pump. But the first question to consider is, does it control scab? For if it does not, further consideration is needless. In the experiments here described, trees sprayed with dry lime-sulfur 4–50, beginning with the pink application, produced an average of 1.3 per cent scabby apples as compared with 60.7 per cent on the unsprayed trees. In the same orchards, on trees sprayed with liquid lime-sulfur, the percentage of scabby apples was 2.7. The conclusion from this is that dry lime-sulfur is fully as dependable for the control of apple scab as is liquid lime-sulfur.

In two successive years, Krout (2) secured as good control of apple scab with dry lime-sulfur as with the liquid. Gardner (6) found dry lime-sulfur as effective

as liquid lime-sulfur against apple scab. In most of the experiments of Keitt and Jones (7), the results with dry lime-sulfur in controlling apple scab were similar to those obtained with liquid lime-sulfur. Massey and Fitch (8) had practically the same results with dry as with liquid lime-sulfur.

Dry lime-sulfur is less bulky to transport. But the material necessary to make 100 gallons of spray costs about twice as much in the dry form as in the liquid. The so-called free sulfur in dry lime-sulfur does not redissolve in water, and this, according to Sears (9), wears out pumps and nozzles more rapidly than does liquid lime-sulfur. It may be added that if this objection is valid, it will hold none the less for dry-mix sulfur-lime, or any sulfur fungicide other than a solution. It seems that the orchardist must decide for himself whether to use dry or liquid lime-sulfur, but he may be sure that the fungicide in either form is efficient for the prevention of infection by the apple scab fungus.

Concentration at Which to Use Dry Lime-Sulfur.

Trees sprayed with dry lime-sulfur 4–50 yielded on the average 1.3 per cent scabby apples as compared to 60.7 per cent on unsprayed trees; while trees sprayed with dry lime-sulfur 2–50 and dry lime-sulfur 3–50 yielded 3.9 and 5.8 per cent scabby apples respectively, as compared to 67.6 per cent on unsprayed trees. The indications are that the use of less than 4 pounds of dry lime-sulfur in 50 gallons will be followed by a slight increase in the percentage of scabby apples.

Krout (2) secured similar results. The check plot yielded 41 per cent scabby fruit, the dry lime-sulfur 4–50 plot yielded 2 per cent, and the dry lime-sulfur 3–50 plot yielded 4 per cent scabby fruit. The difference was slight in 1922 as it is in 1923, but the variation is in the same direction.

Whether liquid or dry lime-sulfur is used, the protection afforded is dependent upon the amount of sulfur present in the diluted spray. The percentage of sulfur is of course not always the same in all dry lime-sulfurs. But in general it may be said that not less than 4 pounds of dry lime-sulfur in 50 gallons are required to supply the same number of pounds of sulfur as are present when 1 gallon of commercial concentrated lime-sulfur, of the usual strength tested in degrees Baumé, is diluted to 50 gallons. According to Dutton (10) the amount of dry lime-sulfur necessary to furnish the equivalent amount of sulfur in 50 gallons is 4.4 pounds, and according to Eustace and Pettit (11), it is 4.8 pounds.

The evidence submitted indicates that reducing the amount of dry lime-sulfur below 4 pounds to 50 gallons is a practice of doubtful economy.

Effect of a Calcium Caseinate Spreader on Control of Scab.

The percentage of scabby fruit was reduced slightly by the addition of calcium caseinate spreader to lime-sulfur. At Frost's, this reduction was from 7.06 to 5.08 per cent scabby fruit; and at Knights', the reduction was from 4.6 to 0.68 per cent. It is a question whether these reductions are in themselves large enough to be significant, but the results are consistently in favor of the use of the calcium caseinate.

The addition of calcium caseinate to sulfur dust did not result in a reduction in the percentage of scabby apples, as compared with the plots dusted with sulfur alone, in either the Frost or the Sabine orchard; and in the Stowe orchard the results were practically the same. In the Frost orchard, the addition of calcium caseinate spreader to sulfur dust was followed by a considerable increase in the percentage of scabby apples.

In the spreader tests of Stearns and Hough (12) the addition of calcium caseinate did not increase the effectiveness of the spray in protecting fruit and foliage from disease and insects. Keitt and Jones (7) secured slightly better control of scab when calcium caseinate was added to lime-sulfur than when the latter was used alone, but it was not considered that the commercial value of its addition was determined. Trees sprayed with lime-sulfur by Parrott, Stewart, and Glasgow (13) yielded 2.1 per cent scabby apples, while trees sprayed with lime-sulfur with calcium caseinate added yielded 4.8 per cent scabby apples. In the experiments of Massey and Fitch (8) trees sprayed with lime-sulfur yielded 1.2 per cent scabby apples, and those trees which were sprayed with lime-sulfur with calcium caseinate added

yielded 1.1 per cent scabby apples. In their dusting experiments, trees which received sulfur yielded 2.6 per cent scabby apples and those which were dusted with sulfur with calcium caseinate added yielded 2.4 per cent scabby apples.

The claim is made that calcium caseinate spreaders improve the adhesiveness of sprays, but it should be noted that Butler and Smith (14) found that the adhesiveness of Bordeaux mixture is not affected by the addition of calcium caseinate. Whatever may be said in favor of the use of calcium caseinate, and there are sound arguments in its favor, it cannot be said that there is sufficient or satisfactory evidence as to its increasing the fungicidal efficiency of lime-sulfur against apple scab to a point of commercial importance. It is probable, however, that the more imperfect the spraying, the greater the benefit to be derived from the use of a calcium caseinate spreader.

Calcium caseinate is further considered in connection with its effect on compatibility of ingredients in combination sprays.

Bordeaux Mixture as Compared with Lime-Sulfur for Applications Before Flower Buds Open.

The Bordeaux mixture used in these experiments was an excess-lime Bordeaux mixture containing 3 pounds of copper sulfate and 10 pounds of lime in 50 gallons of water. This is referred to in the abbreviated language of practice as 3–10–50 Bordeaux mixture. It was used, rather than a Bordeaux mixture containing copper sulfate and lime in the ratio 1:1, because it has been found to be somewhat safer to the sprayed tree.

In the preparation of Bordeaux mixture, the diluted copper sulfate solution and the diluted milk-of-lime may be poured together into a third barrel or into a spray tank, and this is a method quite generally followed. But it requires some special equipment and involves unnecessary labor. It is important that at least one of the stock solutions, either copper sulfate or lime, be diluted before the other and concentrated one is added to it, but as Butler (15) has shown, it is not necessary that both be diluted before mixing. In practice, it is sufficient to place the copper sulfate stock solution in the spray tank when it is about three-fourths full of water; then, with the agitator running, add the undiluted stock solution of the lime, and fill the tank with water. The Bordeaux mixture used in these experiments was prepared in this way.

In many experiments where Bordeaux mixture and lime-sulfur have been compared, it has been found that the former has a somewhat greater fungicidal efficiency than the latter against apple scab. Unfortunately, Bordeaux mixture usually burns the fruit and foliage of the apple. The results of many experiments are well illustrated by those of Krout (2) who found that even an excess-lime Bordeaux mixture of 3–10–50 formula, when used for all applications, russeted the fruit and burned the foliage severely. For this reason, the use of Bordeaux mixture throughout the spraying season was not attempted in 1923. It was, however, used on certain plots for the pink, or the prepink and pink applications, followed by lime-sulfur for later applications.

The plot in the Frost orchard which received three applications of liquid lime-sulfur yielded 2.1 per cent scabby apples, while the plot which received Bordeaux mixture for the pink application and liquid lime-sulfur for the calyx and last applications yielded 1.7 per cent scabby apples. This is too small a difference to have any significance. The plot which received the prepink and pink applications of Bordeaux mixture followed by liquid lime-sulfur for the later applications yielded 0.6 per cent scabby fruit. This reduction in the amount of scabby fruit cannot be attributed entirely to the substitution of Bordeaux mixture for lime-sulfur since this plot received one extra application; namely, the prepink. The results in Frost's orchard do not show that any benefit is to be derived from the substitution of Bordeaux mixture for lime-sulfur for the early application.

At the Knights orchard, Bordeaux mixture was substituted for dry lime-sulfur in one case and for liquid lime-sulfur in another for the pink or prepink and pink applications. The plot sprayed with dry lime-sulfur throughout the season yielded 1.7 per cent scabby fruit, and the plot on which Bordeaux mixture was substituted for dry lime-sulfur at the time of the pink application yielded practically the same; namely, 1.06 per cent scabby fruit. No benefit from the substitution of Bordeaux

was proved in this case. The plot sprayed with liquid lime-sulfur throughout the spraying season beginning with the pink application produced a slightly smaller percentage of scabby apples than did the plot which received Bordeaux mixture at the prepink and pink applications followed by liquid lime-sulfur for the calyx and fourth summer spray.

We have no evidence at either of these orchards that Bordeaux mixture is preferable to lime-sulfur for the prepink and pink applications. The labor involved in preparing Bordeaux mixture is sufficient to swing the scale against it in the absence of more evidence in its favor.

Dr. O. R. Butler states (in correspondence) that in his experiments in New Hampshire in 1922 where a spray schedule of lime-sulfur alone was followed, there was 67.5 per cent scabby fruit; while the substitution of Bordeaux mixture for the pink application reduced the amount to 49.2 per cent. Krout (2) reports that in the Sabine orchard in 1922 the substitution of Bordeaux mixture for lime-sulfur at the pink application did not reduce the percentage of scabby fruit, as compared with results following the use of lime-sulfur alone; in fact, in the case of both dry and liquid lime-sulfur, when Bordeaux mixture was substituted there was a larger percentage of scab. At the Knights and the Frost orchards, however, there was a slight decrease in the amount of scab when Bordeaux mixture was substituted for the pink application; in the case of liquid lime-sulfur this decrease was from 4 to 2 per cent in one orchard and 2 to 0 per cent in another, and in the case of dry lime-sulfur the decrease was from 8 to 3 per cent in one orchard and 2 to 1 per cent in another. We may conclude that although Bordeaux mixture under some conditions may prove slightly superior to lime-sulfur for the pink spray, there is, nevertheless, abundant evidence of the completely satisfactory control of apple scab by lime-sulfur throughout the spraying season; and it does not appear, therefore, that we have sufficient reason to devote extra labor to the preparation of Bordeaux mixture.

Atomic Sulphur.

The proprietary sulfur fungicide, Atomic Sulphur, was used in two orchards with a view to comparing it with lime-sulfur for its fungicidal efficiency and its toxicity to the sprayed tree. Enough of this material to make 100 gallons costs more than three times as much as the liquid lime-sulfur necessary to make an equal amount. Atomic Sulphur, therefore, needs to show very decided advantages over lime-sulfur if it is to compete with it in the spraying of apples.

There was this year no injury to fruit or foliage on trees sprayed with lime-sulfur or with Atomic Sulphur. It was, therefore, impossible to compare them as regards toxicity to the sprayed tree.

Mason (16) found that when apple trees were sprayed with a combination Atomic Sulphur-lime-lead arsenate spray, the foliage was uninjured, while under the same climatic conditions, foliage and fruit were burned by the lime-sulfur-lead arsenate combination.

Atomic Sulphur was used by the writer at the rate of 7 pounds to 50 gallons of water, and when it was used in combination with arsenate of lead, 4 pounds of lime slaked into a milk were added to each 50 gallons, as directed by the manufacturers. At one of the orchards, the results were as follows: Atomic Sulphur, 4.2 per cent scabby fruit; liquid lime-sulfur 2.1 per cent scabby fruit; dry lime-sulfur 4–50, 1.03 per cent scabby fruit. At this orchard, the control secured by Atomic Sulphur was somewhat surpassed by both dry lime-sulfur and liquid lime-sulfur. At the other orchard, the percentages of scabby fruit were as follows: Atomic Sulphur, 3.9 per cent; dry lime-sulfur 3–50, 4.6 per cent. At this orchard also, the results with the two materials are very nearly alike.

If Atomic Sulphur has any advantages over lime-sulfur, they are not to be found in relative efficiency in scab control, but rather in degrees of difference in toxicity to the sprayed plant. Apple orchards in which peaches are planted as fillers are sometimes sprayed with Atomic Sulphur because of the known danger to peaches in leaf from the use of commercial lime-sulfur. When this is done, we may be sure that the apples have received treatment with a fungicide which can protect them against scab infection.

Compatibility of the Ingredients in the Combination Spray as Affected by Addition of Lime, Calcium Caseinate, and Order of Mixing.

Apples are not often sprayed with lime-sulfur alone. They are now more often sprayed with a mixture of lime-sulfur, lead arsenate, nicotine sulfate, and calcium caseinate. The reaction between lead arsenate and lime-sulfur has been studied by Ruth (17) and others, and it is known that both of these materials are somewhat decomposed, one of the results being the formation of the black sludge, lead sulfide. Relative blackness of the mixture is an indicator of its lack of desirable qualities. So far as is known, the addition of nicotine sulfate does not affect this reaction. It has been shown by numerous investigators that the addition of arsenate of lead to lime-sulfur increased the fungicidal value of the latter. Although the use of such a combination spray controls apple scab as well or probably better than lime-sulfur alone, the formation of soluble arsenic as a result of the reaction increases the danger of foliage burning.

It has been found by Robinson (18) that by the addition of lime to this combination spray, the percentage of the soluble, and therefore dangerous, arsenic in the combination spray can be reduced. After standing two days, most of the lime-sulfur with lime added remained unchanged, while in lime-sulfur alone, the desirable polysulfide sulfur had all been changed into lead sulfide or thiosulfate. Bourne (19) modified Robinson's method by adding milk-of-lime to lead arsenate and then adding the two together to diluted lime-sulfur. He found this resulted in very little sediment or blackening. He diluted lime-sulfur till the spray tank was nearly full. Lime (at the rate of 10 pounds to 100 gallons of the total mixture) was slaked and water added to make a milk. Arsenate of lead was stirred into the milk-of-lime, which was then strained into the spray tank with the agitator running. Krout (2) compared liquid lime-sulfur with liquid lime-sulfur plus lime in the field. In each of the three orchards where he used it, there was no russeting of the fruit by either lime-sulfur alone, or lime-sulfur with lime added, and so the benefit of the addition of lime in reducing burning was not shown. In each of the three orchards sprayed by Krout, the addition of lime to lime-sulfur was followed by an increase in the percentage of scabby fruit over the percentage on trees sprayed with lime-sulfur without lime, the increases being 10, 3, and 8 per cent, respectively.

In the experiments of 1923, there was no russeting or burning on trees sprayed with lime-sulfur or on those sprayed with lime-sulfur plus lime. Hence in 1923, as in 1922, it was impossible to prove that the addition of lime to lime-sulfur reduced the toxicity of the fungicide to the sprayed tree. In both of the orchards where these materials were compared in 1923, a larger percentage of scabby apples was produced on trees sprayed with lime-sulfur plus lime than on trees sprayed with lime-sulfur without lime added, the increase being 1.2 per cent in one case and 5.3 per cent in the other. The indications are that the addition of lime to the lime-sulfur-lead arsenate combination spray reduces somewhat the fungicidal efficiency of the latter. In seasons when climatic conditions result in toxicity to the sprayed tree by the lime-sulfur-lead arsenate combination spray, it is possible that any small decrease in fungicidal efficiency coincident with the addition of lime would be more than offset by the decreased danger of burning described by Robinson (loc. cit.) and Bourne (loc. cit.). However, further experimental evidence is needed.

According to Regan (20) the addition of calcium caseinate spreader to lime-sulfur-lead arsenate combination spray prevents the usual decomposition and formation of black sludge. He found two pounds of calcium caseinate to be more effective in preventing this decomposition than ten pounds of hydrated lime. Lovett (21) also reports that the addition of calcium caseinate materially delays the reaction between lime-sulfur and lead arsenate in the combination spray.

Laboratory tests were made by the writer to compare the formation of black sludge in the combination spray with and without the addition of calcium caseinate. Without calcium caseinate, the color of the mixture was dark citrine[1] and with it the color was yellowish citrine, that is, considerably lighter. After standing three minutes the sludge precipitated without calcium caseinate was nearly twice

[1] Colors determined by comparison with Ridgway, Robert. Color Standards and Nomenclature. Washington, 1912.

as much as the sludge in the mixture containing calcium caseinate. Apparently the addition of calcium caseinate physically improves the mixture.

In filling the spray tank, five ingredients are or may be used, *i.e.*, water, lime-sulfur, lead arsenate, nicotine sulfate and calcium caseinate. After the water is in the tank, there are twenty-four different orders in which the other ingredients may be added. The manufacturers of calcium caseinate recommend that it be added to the water in the spray tank, with the agitator running, before the other materials are added. According to Anderson and Roth (22) the lime-sulfur is first diluted, the lead arsenate added to it with agitation, and then the nicotine sulfate added. After putting the calcium caseinate in the water in the spray tank, this is probably the order most commonly followed. Britton (23) recommends the following order for filling the spray tank: first, clean water; second, nicotine sulfate; third, calcium caseinate (if used); fourth, lead arsenate; and fifth and last, lime-sulfur. He says that when mixed in this order, especially if calcium caseinate is present, little or no discoloration or precipitation of brown sludge follows.

In laboratory tests made by the writer, the ingredients were mixed in the order named by Britton; the resulting mixture was buffy olive in color, with little precipitation. In another test they were mixed in the following order: water, calcium caseinate, lime-sulfur, lead arsenate, and nicotine sulfate. The color of this mixture was ivy green, considerably darker, with more precipitation. Several other orders of mixing were compared and the best results, based on a color test and relative sludge formation, were obtained by the following sequence after the water: first, calcium caseinate; second, nicotine sulfate; third, lead arsenate; and fourth, lime-sulfur.

Spore germination tests made with the conidia of the apple scab fungus showed that the fungicidal efficiency of the combination spray is not impaired by any order of mixing tested. But the order of mixing does affect the physical qualities of the mixture and very probably the burning of the sprayed tree. It should be added that when light colored lime-sulfur combination spray is desired, special attention should be given to washing out the spray tank. The use of calcium caseinate results in a decidedly lighter colored mixture.

Results of Dusting Treatments.

A rather extensive literature on the results of dusting for the control of apple scab has come into existence. The results do not all agree, but perhaps they are no more inconsistent than the published results of spraying experiments. In general, the control of apple scab by the use of dusts has been surpassed by that of liquid sprays. This is not surprising when we consider that spraying is a much older orchard practice than is dusting. Our knowledge of the use of liquid sprays and the schedule for their application to the apple is relatively advanced. Dusts have been used in conformity with the spray schedule, rather than according to any special dusting schedule.

It should be noted that no experiments have been conducted in Massachusetts which directly compare the results of spraying with those of dusting. Owing to the topography and plan of the several orchards, spraying and dusting experiments have been carried on in separate orchards or in separate parts of the same orchard with one check plot for the spray treatment and another for the dust treatment.

In the orchards dusted by Krout (2) in 1922 the average percentage of scabby fruit in the check plots was 75.8 and the average percentage of scabby fruit in the plots dusted with sulfur was 17.2. In the orchards sprayed by Krout, the average percentage of scabby fruit in the check plots was 79.0 and the average percentage of scabby fruit in the plots sprayed with dry lime-sulfur 4–50 was 8.0. It is evident that the dust did not give a control equal to that of the spray. The results of Massey and Fitch (8) were: in one orchard, check 93.3 per cent scab, and sulfur dust 13.5 per cent scab; in another orchard, check 43.5 per cent scab and sulfur dust 3.1 per cent scab. In an orchard dusted by Parrott, Stewart, and Glasgow (13), the results were 83.9 per cent scab in the check, and 47.8 per cent scab in the plot dusted with sulfur. Results from other years and other states could be selected either in favor of or against dusting.

In 1923, the dusting experiments here reported were conducted in three orchards. At the Stowe and the Sabine orchards, the dusting schedule consisted of five appli-

cations, *i.e.*, prepink, pink, calyx, fourth dust and fifth dust. At the Frost orchard, the trees were dusted four times, no prepink application being used.

In the Stowe orchard, where check trees yielded 37 per cent scabby fruit, trees dusted with sulfur yielded 3.7 per cent scabby fruit. At the Sabine orchard, trees dusted with sulfur bore 0.5 per cent scabby fruit, and on the check trees 48 per cent of the fruit was scabby. At the Frost orchard, where no prepink application was used, trees dusted with sulfur yielded 16.9 per cent scabby fruit, as compared with 84.5 per cent scabby fruit in the check. Sulfur dust controlled apple scab satisfactorily when applications began with the prepink, but not when the prepink application was omitted.

Calcium caseinate was thoroughly mixed with sulfur at the rate of 5 pounds of calcium caseinate to 95 pounds of sulfur. This sulfur-calcium caseinate dust was used in three orchards in plots adjoining plots dusted with sulfur only. In every case, apple scab was controlled better by sulfur alone than by sulfur with calcium caseinate added.

Plots were also dusted according to a schedule which included the use of a copper dust for the prepink and pink, or the pink applications followed by sulfur dust for later applications. At two of the orchards, there was less scab following the use of sulfur throughout the season than when copper dust was substituted for sulfur for the applications before the flower buds opened. At the other orchard, there was only a negligible difference between the amounts of scab following the two different methods of treatment. No experimental evidence was secured to indicate an advantage in using copper dust instead of sulfur dust for the early applications.

Control of Primary Infection on Leaves.

As the season advances, the work of the fungicide and the conditions under which it acts become entirely different from what they were at the first of the spraying season. There is naturally and usually an increase in the mean temperature. At the time of the early applications, all infection is from the winter spores. As soon as scab lesions appear on the young leaves, there is an increasing possibility of infection by the summer spores. In some springs, the trees are for a few days, or even a few weeks, in danger of infection from both the winter and summer spores at the same time. In the absence of sufficient moisture the ejection of the winter spores may be prolonged until after the appearance of scab on the leaves.

In 1923, ejection of winter spores from the dead leaves beneath the trees was first observed on May 2. Spore ejection continued till June 16, after which none was observed. The first scab symptoms were found on the leaves May 22. It is evident from this that the first winter spores to be ejected did not infect the trees, for the incubation period with these spores of the apple scab fungus was found by Wallace (4) to be eight to fifteen days. During the period in which winter spore ejection continued, there was rain on ten days. Whenever the leaves were wet by rain, winter spore ejection was stimulated, but it was fully as abundant on certain days when the leaves were wet with heavy dew. Winter spores were not ejected in relatively great numbers at any time the last spring. Wallace (loc. cit.) reports that in order for winter spores to infect the trees, the trees must remain wet 8 to 10 hours. Such was the condition on May 12 and 21 and on June 8, and it is probable that much of the primary infection took place on these dates.

In order to secure more information on the relative fungicidal efficiency of the several treatments, the percentages of infected leaves on trees June 18 were determined. In the Frost sprayed orchard, there were at this time 39 per cent scabby leaves on the check trees, and from 0.1 to 0.3 per cent scabby leaves on the sprayed trees, with only negligible differences between the several spray treatments. All the spray treatments were practically successful in preventing the primary infection. The results were essentially the same in both of the Knights orchards, where there were 15 and 20 per cent scabby leaves on unsprayed trees, and 0.1 to 0.2 per cent scabby leaves on sprayed plots, again with negligible differences between the different spray treatments.

Upon examining the dusted orchards, it was found that the primary infection had not been as satisfactorily prevented. In one orchard where the dust treatments began with a prepink application, the check trees had 41 per cent scabby leaves, and the dusted trees had 8 to 9 per cent scabby leaves, with only minor differences between the different dust treatments. In another orchard dusted in

the same way, there were 15 per cent scabby leaves on the check trees and 3 to 4 per cent scabby leaves on the dusted trees. In the third orchard, where no prepink application was used, there were at this time 53 per cent scabby leaves on the check and 21 to 24 per cent scabby leaves on the dusted trees. This indicates the necessity of a prepink application if dust is to control the primary infection. But even where both prepink and pink applications of dust were made, relatively more primary infection occurred than in the sprayed orchards. As is explained elsewhere, the dust treatments in the orchards where dusting began with a prepink application, were entirely satisfactory in preventing the further spread of scab, that is, in preventing infection later in the season by the summer spores. It would appear that if dust is equally as efficient as liquid spraying in controlling the spread of scab during the summer, it is less efficient in preventing the primary infection in early spring. If such is the case, then for those who own both duster and sprayer, a safer procedure would be to use the sprayer for the pink application and the duster for later ones. It should not be overlooked, however, that dust satisfactorily controlled scab on the fruit when the dusting schedule included both a prepink and pink application.

Effect of Fungicides on the Tree.

The literature contains references to increased dropping of the fruit following the use of lime-sulfur. There was this year in the experimental orchards no more dropping of the fruit following any of the several treatments than that which occurred on the check trees.

There was only a negligible amount of injury to fruit or foliage on any of the sprayed or dusted plots. The trees used are McIntosh. Although burning was absent in the experimental plots, it was seen on the fruit of Baldwins following the application of sulfur dust. Childs (3) and others report that sulfur dust may cause an injury to apple fruit similar to that of lime-sulfur solution. The relation of sulfur dust burning to temperature in the case of varieties susceptible to burning needs to be further considered. As has been pointed out by Safro (24) some cases of injury attributed to lime-sulfur are primarily cases of sunburn, and the same is probably true of injury by sulfur dust. The absence of spray injury from all plots made it impossible to learn to what extent the addition of lime to lime-sulfur decreases burning, and how the latter fungicide compares with Atomic Sulphur in this respect on the apple.

Relation of Temperature of the Season to the Fungicidal Efficiency of Sulfur.

We have as yet no data on the temperature necessary for sulfur to prevent the germination of the winter spores of the apple scab fungus. Doran (25) has shown that sulfur prevents the germination of the summer spores of this fungus when the temperature is 78.8° F. for five hours. If the temperature is higher, less time is necessary and if the temperature is lower, more time is necessary. This temperature or above it was recorded in the experimental orchards on fifty days between May 7 and August 31. As the results show, the temperature conditions of the season were such as to insure the fungicidal action of sulfur, and so prevent the germination of the conidia.

If there had been fewer days during this period when the temperature reached the necessary point, it is probable that the results with Bordeaux mixture and copper dust as compared with sulfur fungicides would have appeared relatively better than proved to be the case.

Summary.

A spray schedule beginning with the pink application controlled apple scab as well as a schedule beginning with the prepink application.

Sulfur dust controlled apple scab satisfactorily when it was applied five times beginning with the prepink application, but not when it was applied four times beginning with the pink application.

Liquid lime-sulfur 1–50 and dry lime-sulfur 4–50 proved of equal fungicidal efficiency for scab control.

Less than 4 pounds of dry lime-sulfur in 50 gallons did not on the whole control scab quite as well as dry lime-sulfur 4–50.

The addition of calcium caseinate spreader to the liquid spray was followed by a very slight decrease in the percentage of scabby fruit.

The addition of calcium caseinate spreader to sulfur dust did not result in a smaller percentage of scabby fruit than when sulfur dust was used alone.

Since there was no injury to the sprayed tree by lime-sulfur-lead arsenate combination spray, it could not be proved that the addition of lime to this spray decreased its toxicity to the sprayed tree.

As good a control of apple scab was secured by the use of lime-sulfur throughout the spraying season as by substituting Bordeaux mixture for lime-sulfur for the applications before the flower buds opened.

Atomic Sulphur controlled the disease as well as did lime-sulfur. Because of the absence of burning it was impossible to determine how they compare in their effect on the sprayed tree.

Sulfur dust throughout the dusting season controlled apple scab as satisfactorily as when copper dust was substituted for sulfur dust for the applications before the flower buds opened.

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APPENDIX.

TABLE I. — *Showing Treatment of Dusted Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit.*

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Fourth (or Third) Summer.		Latest Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
Stowe	1	Copper-lime-arsenic-dust	May 5	Copper-lime-arsenic-dust	May 10	Sulfur dust	May 21	Sulfur dust	June 11	Sulfur dust	July 18	2.9
	2	Sulfur dust	5	Sulfur dust	10	Sulfur dust	21	Sulfur dust	11	Sulfur dust	18	3.7
	3	Check (no treatment)										37.0
	4	Sulfur dust plus calcium caseinate	5	Sulfur dust plus calcium caseinate	10	Sulfur dust plus calcium caseinate	21	Sulfur dust plus calcium caseinate	11	Sulfur dust plus calcium caseinate	18	3.9
Frost	1	Check (no treatment)										84.5
	2			Sulfur dust	8	Sulfur dust	22	Sulfur dust	13	Sulfur dust	19	16.9
	3			Sulfur dust plus calcium caseinate	8	Sulfur dust plus calcium caseinate	22	Sulfur dust plus calcium caseinate	13	Sulfur dust plus calcium caseinate	19	30.7
	4			Copper-lime-arsenic dust	8	Sulfur dust	22	Sulfur dust	13	Sulfur dust	19	17.6
Sabine	1	Check (no treatment)										48.0
	2	Copper-lime-arsenic dust	4	Copper-lime-arsenic dust	9	Sulfur dust	24	Sulfur dust	12	Sulfur dust	17	4.8
	3	Sulfur dust	4	Sulfur dust	9	Sulfur dust	24	Sulfur dust	12	Sulfur dust	17	0.5
	4	Sulfur dust plus calcium caseinate	4	Sulfur dust plus calcium caseinate	9	Sulfur dust plus calcium caseinate	24	Sulfur dust plus calcium caseinate	12	Sulfur dust plus calcium caseinate	17	0.7

TABLE II. — *Showing Treatments of Sprayed Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit.*

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Latest Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
Frost	1		May	Dry lime-sulfur 3-50 plus calcium caseinate	May 7	Dry lime-sulfur 3-50 plus calcium caseinate	May 24	Dry lime-sulfur 3-50 plus calcium caseinate	June 13	5.08
	2			Dry lime-sulfur 3-50	7	Dry lime-sulfur 3-50	24	Dry lime-sulfur 3-50	13	7.06
	3			Dry lime-sulfur 4-50	7	Dry lime-sulfur 4-50	24	Dry lime-sulfur 4-50	13	1.03
	4			Dry lime-sulfur 2-50	7	Dry lime-sulfur 2-50	24	Dry lime-sulfur 2-50	13	5.07
	5	Dry lime-sulfur 3-50	3	Dry lime-sulfur 3-50	7	Dry lime-sulfur 3-50	24	Dry lime-sulfur 3-50	13	1.2
	6	Check (no treat-ment)								76.0
	7	Bordeaux mixture	3	Bordeaux mixture	7	Liquid lime-sulfur	24	Liquid lime-sulfur	13	0.6
	8			Bordeaux mixture	7	Liquid lime-sulfur	24	Liquid lime-sulfur	13	1.7
	9			Liquid lime-sulfur	7	Liquid lime-sulfur	24	Liquud lime-sulfur	13	2.1
	10			Liquid lime-sulfur plus lime	7	Liquid lime-sulfur plus lime	24	Liquid lime-sulfur plus lime	13	3.3
	11			Atomic Sulphur	7	Atomic Sulphur	24	Atomic Sulphur	13	4.2

TABLE II. — *Showing Treatments of Sprayed Plots with Dates of Applications, Materials used and Percentage of Scabby Fruit* — Concluded.

Orchard.	Plot No.	Prepink.		Pink.		Calyx.		Latest Summer.		Per Cent Scabby Fruit.
		Material.	Date.	Material.	Date.	Material.	Date.	Material.	Date.	
Knights (A)	1	Bordeaux mixture	May 3	Bordeaux mixture	May 8	Liquid lime-sulfur	May 23	Liquid lime-sulfur	June 14	4.9
	2			Bordeaux mixture	8	Dry lime-sulfur 4–50	23	Dry lime-sulfur 4–50	14	1.06
	3			Liquid lime-sulfur plus lime	8	Liquid lime-sulfur plus lime	23	Liquid lime-sulfur plus lime	14	8.6
	4			Liquid lime-sulfur	8	Liquid lime-sulfur	23	Liquid lime-sulfur	14	3.3
	5	Check (no treatment)								45.5
	6	Dry lime-sulfur 3–50	3	Dry lime-sulfur 3–50	8	Dry lime-sulfur 3–50	23	Dry lime-sulfur 3–50	14	4.8
	7			Dry lime-sulfur 4–50	8	Dry lime-sulfur 4–50	23	Dry lime-sulfur 4–50	14	1.7
Knights (B)	1			Dry lime-sulfur 2–50	8	Dry lime-sulfur 2–50	23	Dry lime-sulfur 2–50	14	2.7
	2			Dry lime-sulfur 3–50 plus calcium caseinate	8	Dry lime-sulfur 3–50 plus calcium caseinate	23	Dry lime-sulfur 3–50 plus calcium caseinate	14	0.68
	3			Dry lime-sulfur 3–50	8	Dry lime-sulfur 3–50	23	Dry lime-sulfur 3–50	14	4.6
	4			Atomic Sulphur	8	Atomic Sulphur	23	Atomic Sulphur	14	3.9
	5	Check (no treatment)								59.3

TABLE III. — *Results of Three Years' Apple Spraying Experiments.*

TREATMENT.[1]	PER CENT SCABBY FRUIT —			
	1923.	1922.	1921.	Average.
Check	58.3	77.0	91.0	75.4
Liquid lime-sulfur	2.7	6.6	8.6	6.1
Liquid lime-sulfur plus lime	5.9	13.6	12.0	10.3
Dry lime-sulfur 4–50	1.3	8.0	6.0	5.1
Dry lime-sulfur 4–50 beginning with prepink	—[2]	0.0	–	0.0
Dry lime-sulfur 3–50	5.8	4.0	–	4.9
Dry lime-sulfur 3–50 beginning with prepink	3.0	–	–	3.0
Dry lime-sulfur 2–50	3.9	–	–	3.9
Dry lime-sulfur 3–50 plus calcium caseinate spreader	2.9	–	–	2.9
Atomic Sulphur	4.0	–	–	4.0
Bordeaux mixture at pink application followed by dry lime-sulfur 4–50	1.0	18.3	–	9.6
Bordeaux mixture at pink application followed by liquid lime-sulfur	1.7	6.0	6.0	4.5
Bordeaux mixture for prepink and pink applications followed by liquid lime-sulfur	2.7	7.0	–	4.8
Bordeaux mixture through season	–	8.6	–	8.6
Sulfur dust beginning with prepink application	2.1	17.2	–	9.6
Sulfur dust beginning with pink application	16.9	–	46.0	31.4
Sulfur dust plus calcium caseinate beginning with prepink application	2.3	–	–	2.3
Sulfur dust plus calcium caseinate beginning with pink application	30.7	–	–	30.7
Copper dust for prepink and pink applications followed by sulfur dust	3.8	–	–	3.8
Copper dust for pink application followed by sulfur dust	17.6	–	–	17.6
Copper dust through season	–	10.2	69.0	39.6

[1] Applications begin with pink unless stated as beginning with prepink.
[2] Blanks in table indicate that the treatment was not given in that year.